Vegetation Dynamics in Everglades National Park Marshes, with Emphasis on Taylor Slough

Contributing Authors:

Thomas Armentano[1]
Mike Ross[2]

1 – South Florida Natural Resources Center, Everglades National Park, 40001 State Road 9336, Homestead, FL 33034-6733

2 – Southeast Environmental Research Center, Florida International University, Miami, FL 33199

Table of Contents

1. Introduction

The marsh communities in Everglades National Park (ENP) and Big Cypress National Preserve are critical components in the biodiversity of the Everglades, both for the structure they provide in support of other biotic elements, and for the intrinsic values of their constituent plant species assemblages. Maintaining or returning these marshes to good condition is a fundamental goal of the federal/state restoration partnership. Furthermore, the restoration plans carry an implicit assumption that providing the "right" hydrology will translate directly and rapidly into the desired marsh community, and on down the line. However, while no one questions that the ecology of these marshes is inextricably bound to their hydrology, they remain complex ecosystems driven by multiple variables, both physical and biological, that could delay or modify the trajectories intended by hydrologic restoration. One avenue of assessing the likelihood of success for hydrologic restoration is to examine the responses of vegetation to hydrologic changes as they have unfolded in the past. In this paper, we examine the temporal and spatial co-variation of vegetation and hydrology in seasonally flooded marshes, focusing specifically on the upper reaches of Taylor Slough during the period 1979-2003.

Over the last half century or so, the topic of vegetation dynamics in Everglades marshes has been addressed by many South Florida wetland research groups, usually in the context of variation in water stage, duration, timing, or quality (e.g., Kolipinski and Higer 1969; Alexander and Crook 1975; Davis et al. 1994; David 1996; Olmsted and Armentano 1997; Busch et al. 1998; Nott et al. 1998; Armentano et al. 2000; Ross et al. 2000; Childers et al. 2003; Ross et al., in press). In these studies, sources of variation in plant community structure other than hydrology, particularly fire and other disturbances, are usually recognized but not analyzed directly. The studies listed above utilize a range of methodologies and combinations of data (aerial photos, plot surveys, qualitative point observations), address different spatial and temporal scales of resolution, and concentrate on different wetland types. All of these studies demonstrate or at least support the notion that water management changes of a magnitude that has occurred frequently during recent decades can induce overwhelming vegetation responses in receiving basins. However, the time frame in which these responses may be expected to run their course is yet unclear.

Two of the studies cited above report on repeated point observations at annual or sub-decadal frequencies in short hydroperiod marshes in Everglades National Park and/or Big Cypress National Preserve (Nott et al. 1998; Armentano et al. 2000). Both studies suggest that substantial changes in vegetation may be realized within a few years. In the pages that follow, we describe more completely vegetation dynamics within the Armentano et al. (2000) transect network in Taylor Slough and adjacent areas, extending the period of observation through 2003 and exploring further the relationships between vegetation change and water management-related variation in hydroperiod. In this analysis, we take advantage of a permanent plot vegetation database extending over 24 years, and a continuous hydrologic record of more than 40 years. Its complex water management history (Van Lent et al. 1993, 1999) makes Taylor Slough an ideal setting for this type of analysis.

2. Study Area

Taylor Slough, a 158 mi^2 freshwater wetland, is comprised of a relatively narrow, sediment-filled channel that broadens southward, flanked by areas 10-30 cm higher in elevation that are much broader than the slough itself. Even in their pre-development condition, the headwaters of Taylor Slough were poorly defined, originating north of the slough in the Rocky Glades, a slightly elevated area west of the Miami Rock Ridge. During wet years, additional water flowed from the much larger Shark Slough to the northwest across the Rocky Glades into the northern portions of Taylor Slough. When sufficiently hydrated, Taylor Slough flowed south to the mangrove forests that border Florida Bay.

As south Florida developed as an agricultural and population center during the last half of the 20th Century, inflows to Shark Slough from the Water Conservation Areas to the north eventually were provided entirely by way of water control structures. In Taylor Slough, the Everglades National Park-South Dade Conveyance System was authorized in 1968 for improving the supply and distribution of water to ENP, while providing for expanded agricultural and urban needs in southern Miami-Dade County (Figure 1). In the process, the L-31 canal was realigned and the L-31W canal was added, thus severing Taylor Slough from its headwaters outside of the park boundaries. In 1980, pump station S332 began to deliver water from the L-31W to Taylor Slough, with the intent of replacing the flows that once originated from the Slough's upper reaches. Regulations for the operation of S332 changed several times during the next 20 years, in response to various environmental concerns (Van Lent et al. 1993, 1999). In a reconfiguration of the water delivery system to Taylor Slough, operation of S-332 was replaced in 1999 by a new station at S-332D. Over the last 3-4 decades, water management in Taylor Slough has taken an uneven course, the ecological effects of which are the subject of this Report.

3. Methods

3.1 Sampling methods

Vegetation data were collected along five line transects of *ca* 2-km length: two representing the headwaters of Taylor Slough (Transects 4 and 5), two in Upper Taylor Slough (Transects 1 and 2), and one in Middle Taylor Slough (Transect 3) (Figure 1). The three lower transects were established by Olmsted and colleagues in 1979 (Olmsted et al. 1980). Armentano et al. (2000) resampled the same quadrats in 1992 (Transect 2), 1995 (Transects 1 and 2), and 1996 (Transect 3). To broaden the sampling domain, Transects 4 and 5 were established and sampled in 1997, and all five transects were resampled in 1999 and 2003.
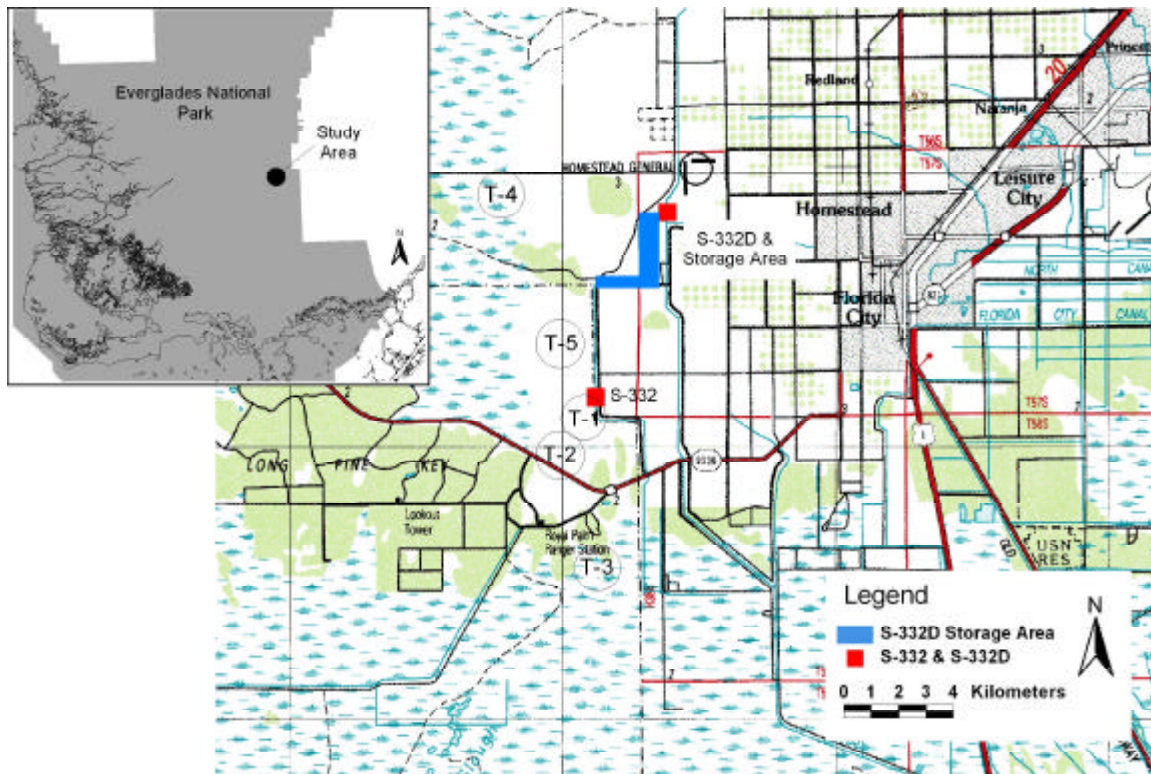
Figure 1. Location of Taylor Slough Sampling transects, S-332 and S-332D water control structures, and storage area on the eastern boundary of Everglades National Park

The rationale for plot selection in Transects 1-3 and 4-5 differed. ENP scientists' objective in 1979 was to establish a baseline for determining the effects of the future operation of the S-332 pump station on two distinct community types: those dominated by *Cladium jamaicense* (sawgrass) and those dominated by *Muhlenbergia filipes* (muhly). Therefore, half of the plots established along Transects 1-3 were subjectively located in *Cladium* stands (C-plots) intersected by the lines, and half were in *Muhlenbergia* stands (M-plots). Furthermore, data from the 1979 survey were only available in summarized form, as means among all C- or M-plots. In contrast to Transects 1-3, the plot locations established in Transects 4 and 5 in 1997 were not selected on the basis of existing cover types, but rather were placed at 100-meter intervals along the transect, adjusting the distances where necessary to avoid tree islands.

To facilitate direct comparison of the sequential surveys, vegetation sampling protocols initiated by Olmsted and colleagues in 1979 (Olmsted et al. 1980) were maintained throughout the study. The corners of twenty 1m x 5m plots were permanently marked along each transect, with each plot divided into five 1 x 1 m quadrats. Cover (per cent of the ground surface covered in a vertical projection) was estimated for all vascular plants in each quadrat. Data were averaged at the level of the plot (5 m^2), i.e., 100 quadrat estimates were used to generate 20 plot estimates per transect. Areas covered by periphyton or devoid of vascular plant material were recorded separately as "open". For the three dominant species (*Cladium jamaicense, Eleocharis cellulosa,* and *Muhlenbergia filipes*), separate cover estimates of live and dead components were made.

4

All observers were trained and tested in visual estimation by the senior investigators, such that there were common participants through the entire 1992-2003 period. The spatial unit for which cover was estimated was 0.25 m^2, or 4 units per quadrat. A frame subdivided into quarters with string defined the observational unit. Blind testing of observer differences showed that discrepancy of species cover estimates among individuals was primarily 15% or less where cover was in the 50% range or above and smaller at lower cover. With rare exception, all individual plants beyond the cotyledon stage were identified in the field, or marked and identified later.

On Transects 1-3, a single elevation was determined for the middle quadrat of each plot with a laser Topcon leveler tied to a permanent benchmark established by professional surveyors. On Transects 4-5, elevations along the transects and at each quadrat per plot were determined by surveying with an auto-level from an established benchmark.

3.2 Analytical methods

Hydrologic models: Multiple linear regression models were developed to understand more fully the changes in water level in relation to rainfall and management-related activities, including deliveries from S-332 and S-332D. The period for which both water level and rainfall data were available was divided into 3 sub-periods; 1) pre-S332 period (1961-1980); 2) S-332-operation period (1980-1999); 3) S-332D-operation period, (1999-2002), hereafter termed ISOP period. For a brief period from 1999 to 2000, water was delivered into the Taylor Slough through both structures S-332 and S-332D. Stage data from ENP hydrologic stations TSB and TS2 were used to calculate daily mean water level in Taylor Slough during dry (November through May) and wet (June through October) seasons between 1961 and 2002. Rainfall data from ENP climatic station RPL was used to calculate total seasonal rainfall during the period. Mean daily flow (cuft/sec) through S-332 and S-332D was used to calculate monthly mean volume of water (million cubic meter/month) delivered to Taylor Slough through these structures in dry and wet seasons during the S-332-operation and ISOP periods.

Eight seasonal models were developed to predict the seasonal mean water level at Taylor Slough Bridge. Models 1A and 2A (wet and dry season, respectively) were based on data from the pre-S332 period only, but were also applied to the S332-operation and ISOP periods to provide an estimate of water levels that would have occurred during 1980-2002 in the absence of delivery. The primary predictor in these models was total rainfall during the period (cm). Inclusion in the models of a term representing water level present at the end of the previous season, i.e., mean daily water level during the prior May or October, resulted in improved model performance during the pre S-332 period (Models 1B and 2B). However, these models were not appropriate for predicting during the delivery period, because the value of the "one-month lag" variable would itself have been affected by delivery. Models 3 and 4, based on the period 1980-20001, included terms for rainfall and volume of water delivered through S-332. These models were applied to the period 1980-1999. Finally, Models 5 and 6, developed from data of 1992-2003, included a term for rainfall and separate terms for delivery from S-332 and S-332D. These models were applied to the years 1999-2003. Models 3-6 were not improved by

including a one-month lag term as an additional predictor.

Vegetation dynamics: We applied a non-metric multidimensional scaling (NMS) ordination (Kruskal 1964), using PC-ORD software (McCune and Mefford 1999), to visualize temporal changes during the study period. The NMS procedure involves an iterative search to position sites along a limited number of axes, such that the rank order of among-site dissimilarities in vegetation composition is replicated as much as possible (McCune and Grace 2002). For these analyses, the Bray-Curtis distance metric was used as a measure of dissimilarity among sites. To minimize the effects of rare species on the ordination, species present in less than 5% of plots were eliminated from the analysis. Cover data were standardized to site total by dividing each species' cover by the total abundance of all species within the plot. To be consistent with the scale of integration of the 1979 vegetation data, the ordinations for Transects 1-3 were applied to data summarized across all C- or M-plots (classification of individual plots was retained throughout the study, regardless of any shift in composition). Site ordinations for Transects 4 and 5 were calculated on a plot level basis.

Differences in plant communities among sampling years were also examined quantitatively by using Analysis of Similarity (ANOSIM). ANOSIM is a non-parametric multivariate analysis used to test for difference in community composition among two or more entities, such as treated and untreated plots (Clarke 1993). This analysis requires replication within groups; in our case, this meant plots within years. Therefore, on Transects 1-3, we analyzed post-1979 data only, testing within M- and C-plots separately. On Transects 4 and 5, we tested for temporal differences among all sample years.

Weighted averaging models for calculation of vegetation-inferred hydroperiod:
Weighted averaging (WA) regression and calibration models (Birks et al. 1990) were developed in two steps. In the regression step, species optima and tolerances for hydroperiod were estimated on the basis of their abundances and observed hydroperiods at 91 locations along three transects, i.e., Transects 4 and 5 from this study, and Transect A from the Cape Sable sparrow habitat study (Ross et al. 2003). In these plots, vegetation was surveyed in the winter and spring of 2003, and hydroperiods were estimated from mean plot elevations and water level records from the 1996-2001 water years at ENP recorders CR-2, NTS-1 and NP-205. The WA species optimum for hydroperiod was calculated by taking the average of all hydroperiods for plots in which the species occurs, weighted by species' relative abundance. The tolerance for each species was estimated as the weighted standard deviation of hydroperiods. We used the C^2 program of Juggins (2003) to calculate species optima and tolerances, and we selected the models that minimized the root mean square error of prediction (RMSE) of 100 bootstrapped estimates from the data set.

In the calibration step, we applied the best WA model to the historical and current vegetation data from the five Taylor Slough transects. Weighted averaging techniques are usually applied to infer the level of an environmental variable in data sets in which it is unknown but species composition is known. Our usage in this case was somewhat different. Here, we examined temporal changes in the vegetation-inferred estimates, with

the intent of shedding light on the responsiveness of the plant communities to annual or longer-term hydrologic variation. The differences in inferred-hydroperiods among years were analyzed with the use of repeated-measures analysis of variance (repeated-ANOVA).

4. Results

4.1 Hydrological changes in Taylor Slough

Water level in Taylor Slough was much higher in the 1980's and 1990's than in the two previous decades (Figure 2). During the pre S-332 period (1961-1980), mean daily water level in the Slough in both dry and wet seasons was significantly correlated with rainfall. In addition, the water level present at the end of the previous season, i.e., mean daily water level during the prior May or October, was also significantly related to the water level in dry and wet seasons, respectively, and inclusion of this term improved the performance of the respective predictive models (Table 1; Figures 3 & 4). When the precipitation-only model derived from data from the pre S-332 period was used to estimate water levels during the S332-operation (1980-1999) and ISOP (1999-2003) periods (see Analytical Methods), predicted water levels were much lower than observed water levels. This incongruity indicated not only that rainfall was not a good predictor during the S-332 operation and ISOP periods, but also that water management activities were apparently raising water levels substantially over what they would have been in a precipitation-driven system.
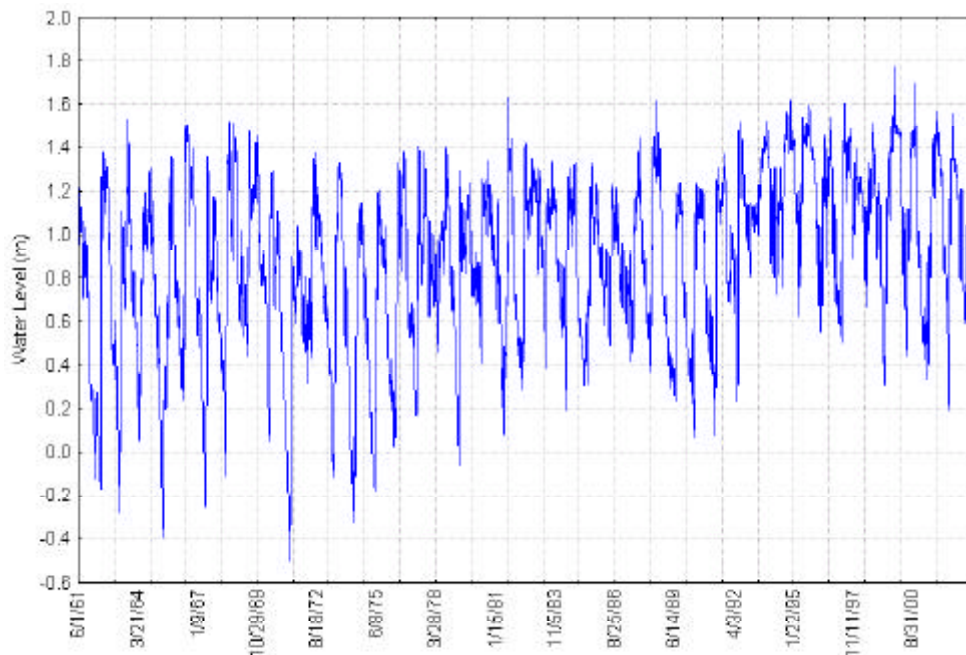

Figure 2. Mean daily water level (m) in Taylor Slough recorded at two ENP stage recorders, TSB and TS2, 1961-2002

Table 1. Linear regression models for the relations of water level to rainfall, S332 and S332 delivery and 1-Month Lag. Significant terms in the model are in bold.

Period	Season	Model	R^2	Standard error of estimate
Pre-S332	Wet	(1A) WL = 58.09 + 2.11*Rainfall	0.382	13.47
		(1B) WL = 63.20 + 1.51*Rainfall + 0.23*1-Month Lag	0.705	9.60
	Dry	(2A) WL = 19.04 + 5.41*Rainfall	0.544	13.12
		(2B) WL = -34.33 + 4.95*Rainfall + 0.51*1-Month Lag	0.713	10.74
S332-Operation	Wet	(3) WL = 87.29 + 1.04*Rainfall + 1.16*S332-Del	0.543	9.47
	Dry	(4) WL = 52.27 + 2.16*Rainfall + 2.79*S332-Del	0.846	9.31
S332D-Operation (ISOP period)	Wet	(5) WL = 108.28+ 0.28*Rainfall + 0.88*S332-del + 0.65*S332D-del	0.586	5.60
	Dry	(6) WL = 63.21+ 2.91*Rainfall + 1.70*S332-del + 0.33*S332D-del	0.890	6.50

During the 22-year S-332 operation and ISOP periods, the mean monthly volume of water delivered through S-322 into Taylor Slough varied greatly, and was much less between 1980 and 1992 (3.8 million cubic meter) than between 1992 and 2003 (13.6 million cubic meter). The delivery of water also varied seasonally, with more water delivered in wet seasons than in dry seasons (Figures 3 & 4). However, the annual variation in water delivery was greater in the dry season than in the wet season.
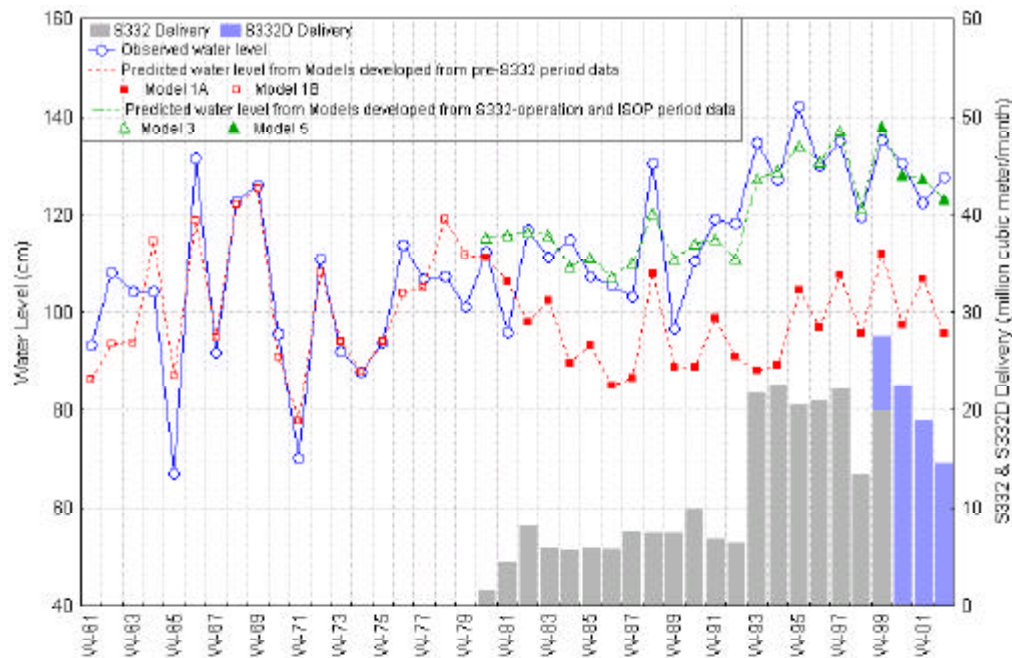

Figure 3. Observed and predicted water level and water flow through S-332 and S-332D into Taylor Slough During the 1961-2002 wet seasons. See Table 1 for details of the models
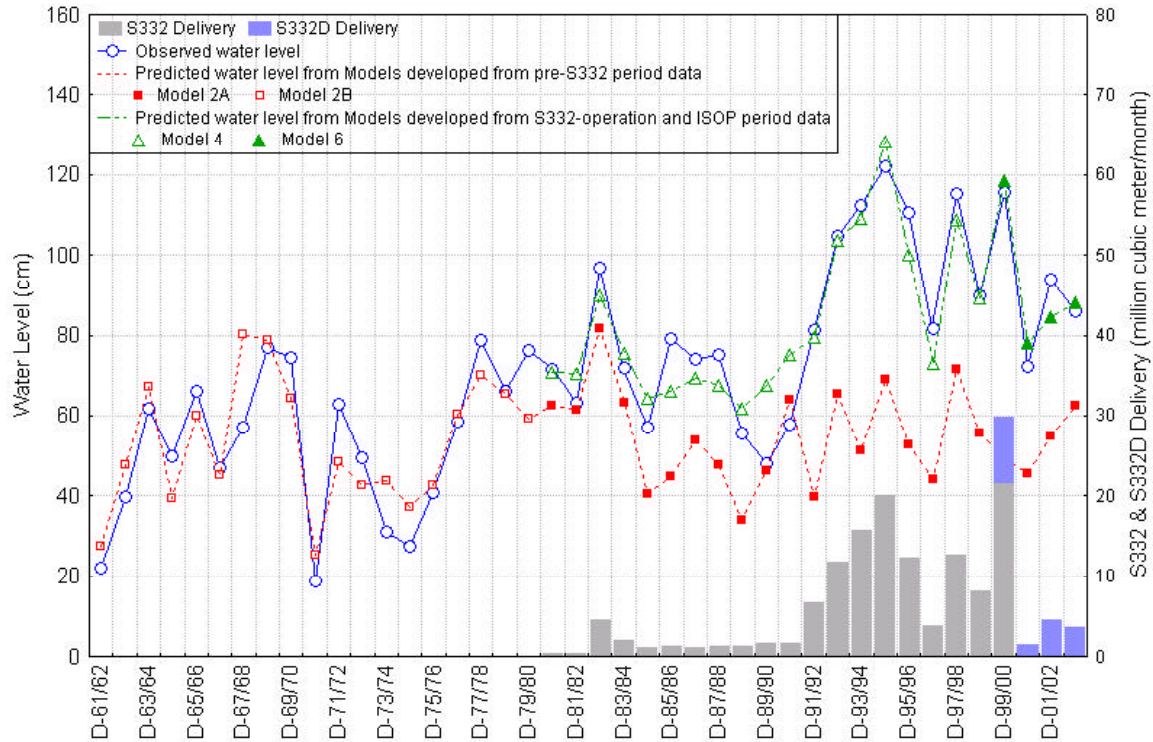
Figure 4. Observed and predicted water level and water flow through S-332 and S-332D into Taylor Slough during the 1961-2002 dry seasons. See Table 1 for details of the models

As these data suggest, water levels in the Slough during 1980-2003 were primarily correlated with the volume of water delivery (Table 1). During these periods, rainfall contributed significantly to the model only in the dry season (R^2 of 2-factor model = 0.846, $p_{rainfall}$ = 0.037), when the delivery from the pumping stations was at its minimum level, but not in wet season (R^2 = 0.543, $p_{rainfall}$ = 0.063). Another important result was that, in contrast to the situation during pre S-332 operation period, the 1-month lag term was not a significant predictor of Taylor Slough water level during the S332-operation and ISOP periods.

In general, the mean daily water level during S-332 operation period was about 30-40 cm higher than in pre S-332 period, and it was much higher in the 1990's than in the 1980's. More recently, the mean daily water level in the Slough again decreased during the ISOP period, primarily because less water was delivered from S-332D in comparison to S-332, which ceased operation in 2000.

4.2 Vegetation patterns along and across the transects

Vegetation composition along Transects 1-3 changed substantially over the study period (1979 – 2003). The NMS ordination indicated that by 1995, M-plots (i.e., muhly-dominated in 1979) on Transect 1 changed in composition to resemble 1979 C-plots (sawgrass-dominated in 1979). This trend continued through 2003 (Figure 5a). Similar patterns were observed in Transects 2 and 3 (Figures 5b & 5c). However, in the C-plots on these two transects, there appeared to be some recovery during the 1999-2003 period

toward the community that was present in 1979. This recent change may indicate that vegetation was responding to the decrease in Taylor Slough water levels during the ISOP period.
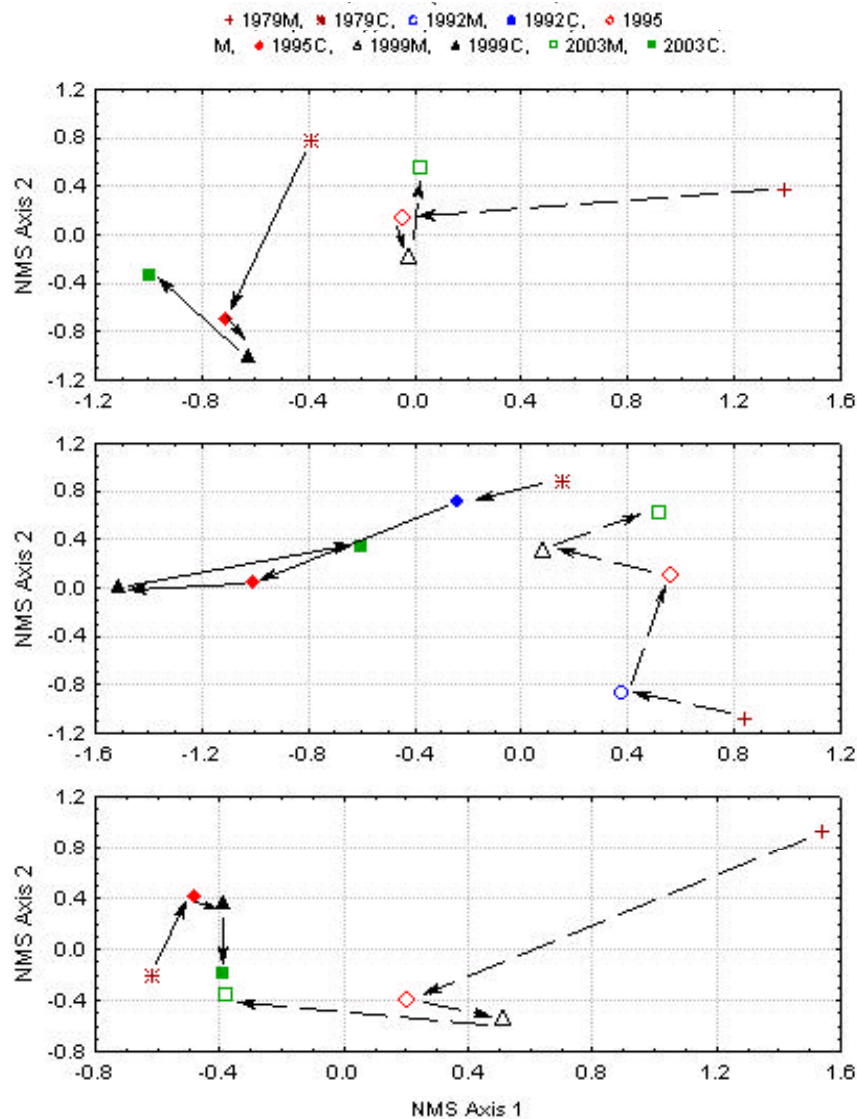

Figure 5. Site scores from NMS ordination, based on relative cover averaged across all Muhly (M; dased line) and all Cladium (C; solid line) plots on Transects 1,2,3 (Stress- 1.15, & 7.63 and .02, respectively) sampled in different years.

The analysis of similarity (ANOSIM) of post-1979 data showed significant overall annual variation for both M- and C-plots on all three transects. Furthermore, most individual between-year comparisons indicated significant differences in composition. The only exceptions were 1995-1999 or 1996-1999 comparisons, which were non-significant for both M-and C-plots on Transect 1, and C-plots on Transect 3 (Table 2).

Table 2: R-statistics and p-values from analysis of similarity (ANOSIM) testing for among-year differences in species composition along Transects 1-5, 1992 – 2003. Plots along Transects 1-3 were grouped in Muhly (M) plots and Cladium (C) plots.

Transect	Plots	Comparisons	R-Statistic	p-value
T1	C-plots	Among all years	0.208	0.001
		1995,1999	0.048	0.172
		1995,2003	0.262	0.003
		1999,2003	0.317	0.002
	M-plots	Among all years	0.212	0.001
		1995,1999	0.036	0.268
		1995,2003	0.302	0.002
		1999,2003	0.292	0.002
T2	C-plots	Among all years	0.568	0.001
		1992,1995	0.670	0.001
		1992,1999	0.913	0.001
		1992,2003	0.785	0.001
		1995,1999	0.132	0.032
		1995,2003	0.470	0.001
		1999,2003	0.425	0.001
	M-plots	Among all years	0.454	0.001
		1992,1995	0.581	0.001
		1992,1999	0.628	0.001
		1992,2003	0.647	0.001
		1995,1999	0.158	0.020
		1995,2003	0.464	0.001
		1999,2003	0.268	0.002
T3	C-plots	Among all years	0.237	0.002
		1996,1999	0.004	0.371
		1996,2003	0.380	0.002
		1999,2003	0.336	0.004
	M-Plots	Among all years	0.474	0.001
		1996,1999	0.389	0.002
		1996,2003	0.495	0.001
		1999,2003	0.583	0.001
T4		Among all years	0.382	0.001
		1997,1999	0.074	0.034
		1997,2003	0.561	0.001
		1999,2003	0.493	0.001
T5		Among all years	0.675	0.001
		1997,1999	0.621	0.001
		1997,2003	0.726	0.001
		1999,2003	0.750	0.001

In 1979, mean total plant cover ranged from a low of 14.5% on Transect 3 up to 49.3% on Transect 1 (Figure 6). In the M-plots, *Muhlenbergia filipes* was the dominant species, with a relative cover of 90%, 77% and 59% on Transects 1, 2 and 3, respectively. In those plots, *Cladium jamaicense* was the next most abundant species, and was the only species with an absolute cover of more than 1%. In the C-plots, *C. jamaicense* was the

most prevalent species, with relative cover values of 34%, 47% and 85% on Transects 1, 2, and 3, respectively. *Centella asiatica* was the second most abundant species in C-plots of Transects 1 and 2, where *M. filipes* was absent. However, *M. filipes* had the second highest relative cover (6%) in C-plots of the Transect 3. *Eleocharis cellulosa*, a major component of long hydroperiod prairie in the Everglades, was absent from M-plots on all three transects, and from C-plots on Transects 2 and 3. *E. cellulosa* was present in 56% of the C-plots of Transect 1, though its cover averaged only 0.6%.
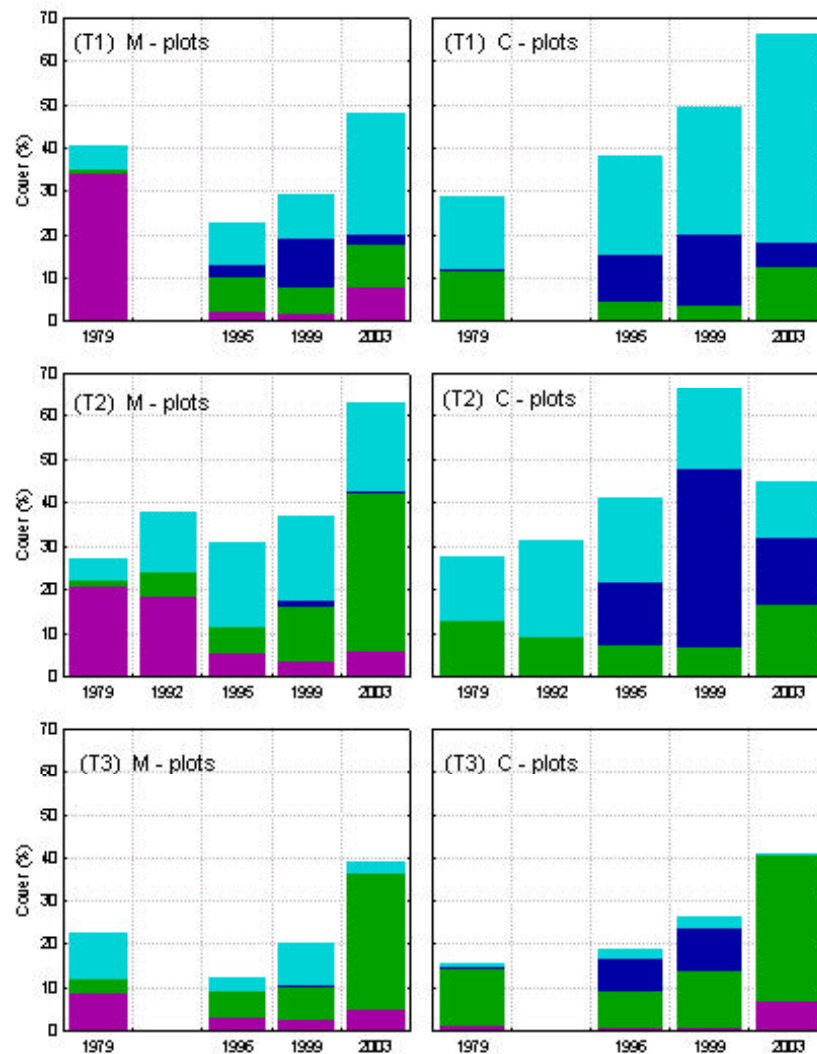

Figure 6. Absolute cover (%) of major species averaged across all M- C-plots on Transects 1, 2, and 3 1979-2003. *Cladium jamaicense* (green), *Eleocharis cellulose* (dark blue), *Muhlenbergia filipes* (purple, Other Species (aqua).

Changes in vegetation composition along Transect 1, 2 and 3 became apparent by 1995, when a substantial decrease in *Muhlenbergia filipes* cover and an increase in *Cladium jamaicense* cover were observed in the M-plots (Figure 6). In the same year, a large decrease in *C. jamaicense* cover was recorded in the transects' C-plots. Changes in *M. filipes* and *C. jamaicense* cover in both plot types were more dramatic on Transect 1 than

on Transect 2 and 3. For example, the absolute cover of *M. filipes* in the M-plots on Transect 1 decreased by 1700% by 1995, compared to 400% and 300% on Transect 2 and 3, respectively (Figure 6). Parallel decreases in *C. jamaicense* cover in C-plots was also observed. In contrast, *C. jamaicense* cover increased significantly in M-plots over the sampling period. *Eleocharis cellulosa*, which was present only in the C-plots of Transect 1 in 1979, became established in M-plots on Transect 1 and 3 by 1995, and later became one of major species in C-plots on all three transects.

The trends in vegetation between 1979 and 1995 continued through 1999, though the changes in *M. filipes* and *C. jamaicense* cover were not as large. However, during this period, the cover of *E. cellulosa* increased in the M-plots on Transect 1 and in the C-plots on all three transects (Figure 6). *E. cellulosa* was the most abundant species in M- and C-plots on Transect 1, with an absolute cover of 11.3% and 16.6%, respectively. Its average cover reached 10% in C-plots on Transect 3, and, at 40%, reached its highest abundance in the C-plots on Transect 2.

The compositional trend between 1999 and 2003 was the opposite of that which had prevailed prior to 1999. Cover of *M. filipes* and *C. jamaicense* increased in M- and C-plots, respectively (Figure 6), and cover of *E. cellulosa* in these plots decreased considerably. *E. cellulosa* was virtually absent (mean cover <0.1%) in the M-plots of Transect 2 and 3, as well as the C-plots of Transect 3. However, the trend of increasing cover of *C. jamaicense* in the M-plots, observed before 1999, continued through 2003. Total cover of all species increased sharply in M-plots in all three transects, and in C-plots in Transects 1 and 3, but not Transect 2.

 Besides *M. filipes, C. jamaicense* and *E. cellulosa*, 26 species exceeded 1% cover in M- or C-plots on Transect 1-3 in any sampling year. However, only six species achieved mean cover >5%. These species were *Baccopa caroliniana, Centella asiatica, Ludwigia microcarpa, Panicum hemitomon, Schizachyrium rhizomatum* and *Spartina bakeri*. Between 1979 and 2003, the mean cover of *C. asiatica* and *S. rhizomatum* increased from 0.15% to 10% and from 0.2% to 12% in the M-plots on Transects 1 and 2, respectively (Figure 7). In the C-plots, the mean cover of *B. caroliniana* in Transect 1 increased from 0.05% to 7.6% in 1999, then decreased precipitously in 2003. In contrast, *P. hemitomon* in Transect 2 C-plots increased continuously after 1979, reaching 32% cover in 2003 (Figure 7). In general, the cover of species with optimum hydroperiod between 150 and 180 days increased in the M-plots on Transects 1 and 2 over the sampling period. In the C-plots, many of these short hydroperiod species were present in 1979, but were either absent or had very low cover in subsequent sampling years. Long hydroperiod species in the C-plots behaved differently. The cover of species with optimum hydroperiods >210 days increased on both transects between 1979 and 1999, then decreased during the ISOP period (Figure 7).

(dashed lines) are: —⚹— *Schizachyrium rhizomatum* (170) -◦- *Centella asiatica* (173) -▫- *Phyla nodiflora* (178). Species with long optimum hydroperiod (solid lines) are: —◆— *Sagittaria lancifolia* (213), —◇— *Rhynchospora tracyi* (258), —▪— *Leersia hexandra* (258), —▲— *Bacopa caroliniana* (264), —▪— *Panicum hemitomon* (267), —⚹— *Paspalidium geminatum* (276), —+— *Pontederia cordata* (292). Hydroperiod optima are given in parenthesis.
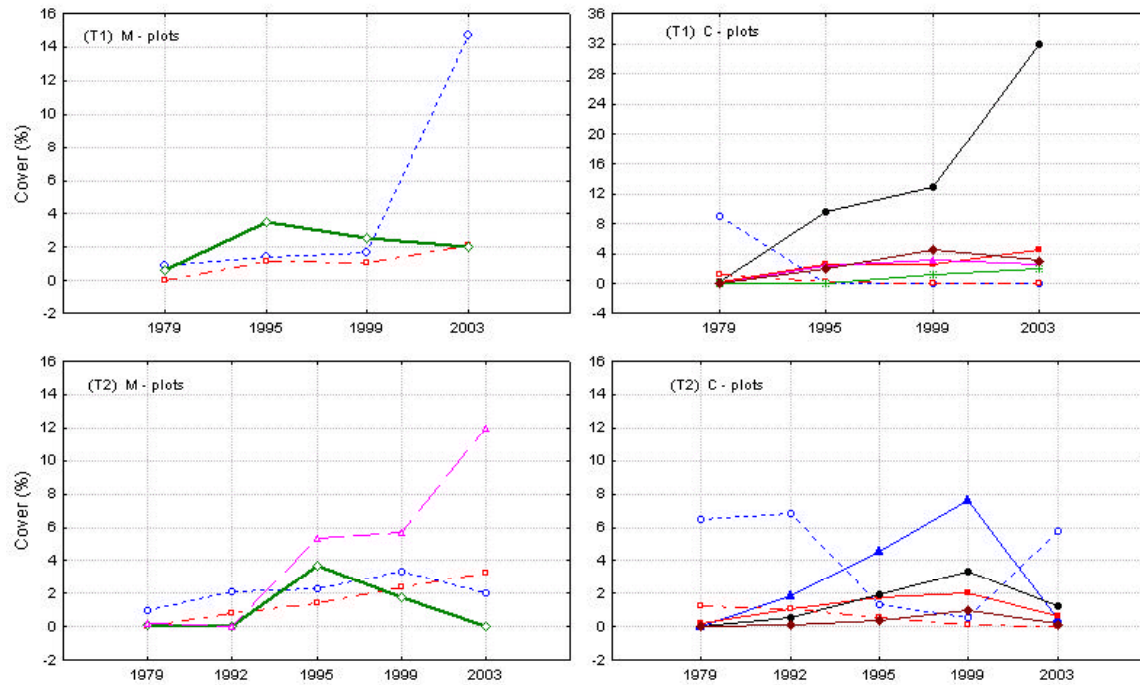

Figure 7. Absolute cover (%) of selected species in M- and C-plots on Transect 1 & 2, 1979-2003. Species with short optimum hydroperiods are noted by dashed lines and species with long hydroperiods are depicted by solid lines (refer to the key above).

Since Transect 4 and 5 plots were not grouped into M and C categories, vegetation composition on these transects was analyzed at the plot level. Like Transects 1-3, these transects also experienced substantial change in vegetation composition over the 6-year sampling period. ANOSIM showed that vegetation composition in 1997, 1999 and 2003 differed significantly from one another (Table 2). The plots were likewise grouped by year in the NMS diagram, indicating a directional change in vegetation along an unidentified gradient (Figure 8).
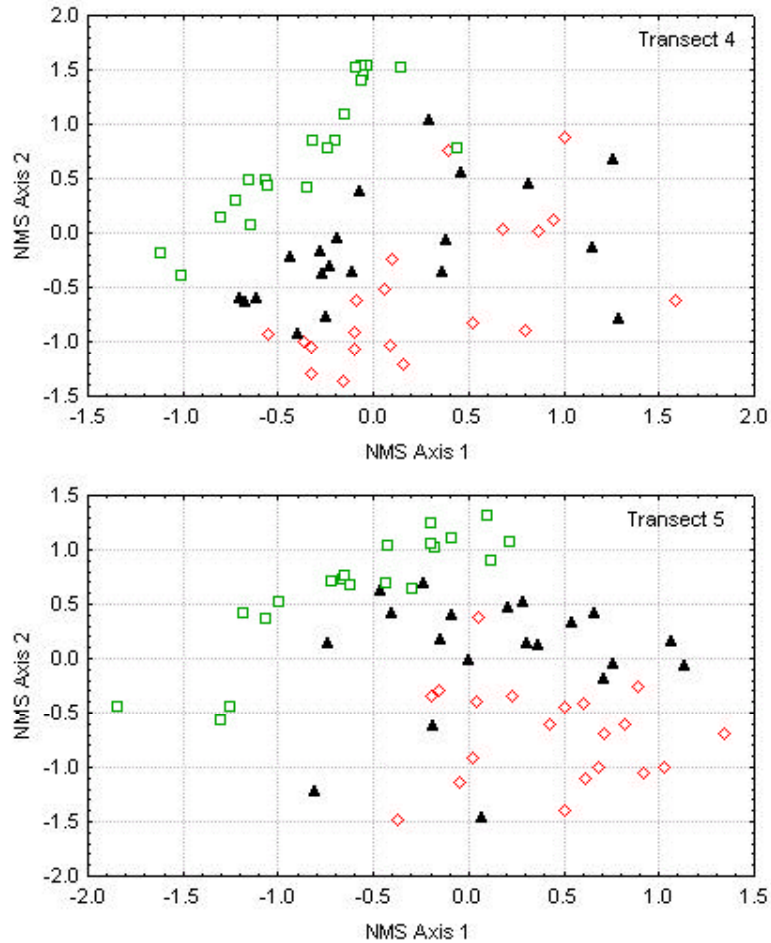
14

Figure 8. Site scores from 2-axis NMS ordination, based on relative cover in plots on Transect 4 and 5
(Stress = 11.5 and 15.6, respectively) sampled in 1997 (red diamonds) 1999 (black triangle)
and 2003 (green square)

Vegetation dynamics on Transects 4 and 5 during 1997-2003 were characterized by a
large increase in total cover that paralleled the trend of increasing cover already noted in
Transects 1-3 in 1999-2003, a period of relatively low water level in Taylor Slough. This
increase was concentrated particularly among the two major species, *Cladium jamaicense*
and *Muhlenbergia filipes* (Figure 9). In the six-year study period, the mean cover of *C.
jamaicense* increased from 3.7% to 37.8%, and from 2.8% to 22.3% on Transects 4 and
5, respectively. The cover of *M. filipes* also increased more than 7-fold on these transects
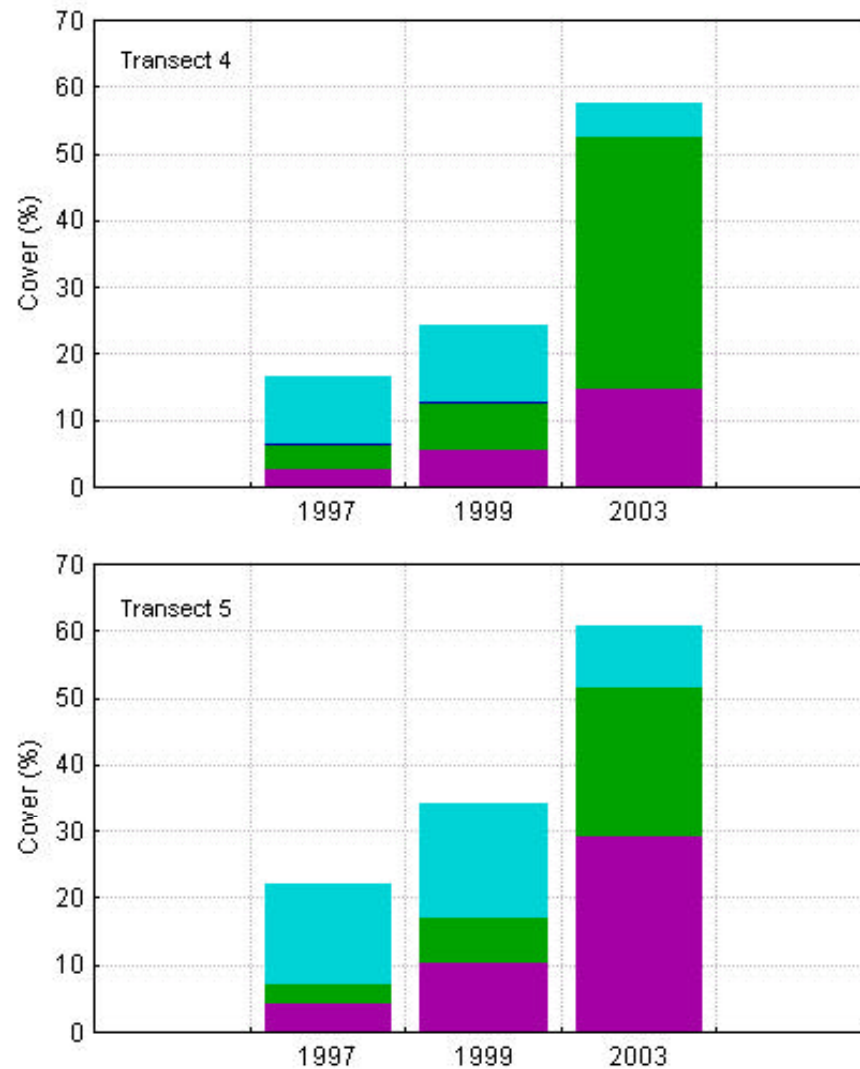(Figure 9).

Figure 9. Absolute cover (%) of major species in plots on Transect 4 and 5 sampled in 1997, 1999, and 2003. *Cladium jamaicense* (green), *Eleocharis cellulose* (dark blue), *Muhlenbergia filipes* (purple, Other Species (aqua).

At the beginning of the 1997-2003 period, species other than *C. jamaicense* and *M. filipes* contributed about two thirds of the total cover on Transects 4 and 5, but no single species stood out. *Centella asiatica* and *Phyla nodiflora* were the only species that had mean cover >1% on Transect 4, and five species (*Centella asiatica*, *Dichanthelium dichotomum, Eragrostis elliottii*, *Panicum tenerum* and *Solidago stricta)* had mean cover >1% on Transect 5. The proportion of total cover contributed by species other than *C. jamaicense* and *M. filipes* decreased significantly by 2003, and the change was more extreme during the ISOP period (1999-2003) than in first two years (1997-1999) (Figure 9). In 2003, these species contributed only 5.8% and 15.3% of the total cover on Transects 4 and 5, respectively, compared to 47.8% and 51% on the same transects in 1999. In 2003, no species had more than 1% cover on Transect 4, and only two species, *Panicum tenerum* and *Schizachyrium rhizomatum*, had >1% cover on Transect 5 (Figure 10).

Species with short optimum hydroperiod (dashed lines) are: —+— *Solidago stricta* (138), —+— *Dichanthelium dichotomum* (165), —■— *Schizachyrium rhizomatum* (170), —○— *Centella asiatica* (173), ⋯○⋯ *Phyla nodiflora* (178). Species with long optimum hydroperiod (solid lines) are: —+— *Eragrostis elliottii* (224), —■— *Panicum tenerum* (232). Hydroperiod optima are given in parenthesis.
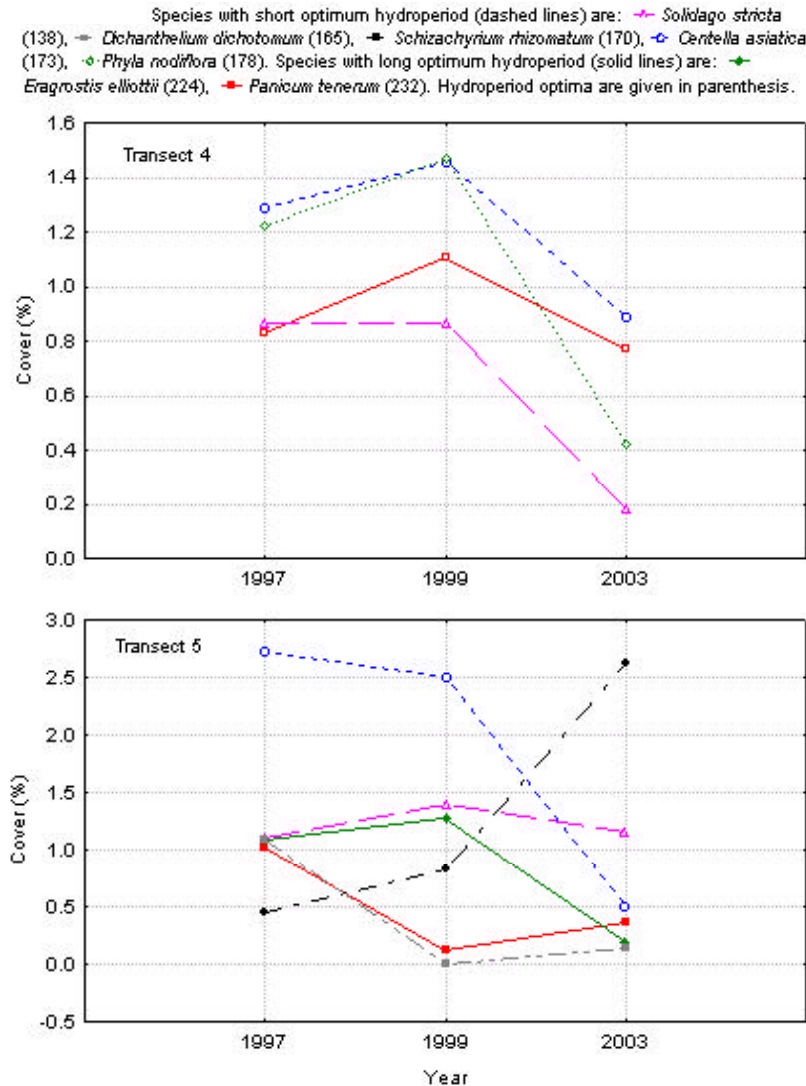

Figure 10. Absolute cover (%) of selected short and long hydroperiod species on Transects 4 & 5 sampled in 1997, 1999, and 2003.

Species richness varied during the study period (Table 3). On Transects 1-3, species richness decreased dramatically between 1979 and 1995, and then remained almost stable through 1999. During the ISOP period, species richness increased in the M- and C-plots on Transect 1, and in the C-plots of Transects 2 and 3. An increase in species richness at the transect level was also observed on Transect 5 during the ISOP period, though the same pattern was not observed at the plot level. On Transect 4, species richness remained nearly stable over the 6-year study period.

Table 3: Species richness (total numbers of species sampled in all plots) on Transects 1-5, 1979-2003. Numbers inside parentheses are mean numbers of species per 5 m^2 plot. Muhly (M) and Cladium (C) plot-types on Transects 1-3 are summarized separately.

Transect/Plot-type	1979	1992	1995/96/97	1999	2003
T1-C	41		22 (9)	19 (9)	21 (9)
T1-M	46		29 (12)	28 (12)	35 (15)
T2-C	47	36 (15)	33 (14)	25 (14)	30 (13)
T2-M	49	30 (12)	35 (14)	36 (14)	36 (14)
T3-C	21		18 (4)	19 (6)	25 (7)
T3-M	28		15 (7)	25 (11)	25 (9)
T4			49 (16)	46 (15)	46 (14)
T5			40 (18)	50 (19)	55 (15)

4.3 Vegetation-hydrology relationships

Many of the changes in species cover described in the last section suggest that higher water level in Taylor Slough during the S332-operation and ISOP periods in comparison to the pre-S332 period (Figure 2) may have had considerable effect on vegetation composition along Transects 1, 2 and 3. To examine this possibility, we analyzed the vegetation-hydrology relationship through the development of a Weighted Averaging (WA) regression and calibration model. The WA model was developed from vegetation cover data collected in 2003 on Transects 4 and 5 (this study) and Transect A within Cape Sable sparrow sub-population A, west of Shark Slough (Ross et al. 2003). Hydroperiods were estimated from mean plot elevations and water level records from the 1996-2001 water years at ENP recorders CR-2, NTS-1 and NP-205. We applied the model to the historical and current vegetation data from the five Taylor Slough transects, and estimated vegetation-inferred hydroperiods for each sampling year during the S332-operation and ISOP periods (Figures 11 & 12). Because 1979 vegetation data were available only in summarized form over M- or C-plots, plot-level inferred hydroperiods were not estimated for that year.
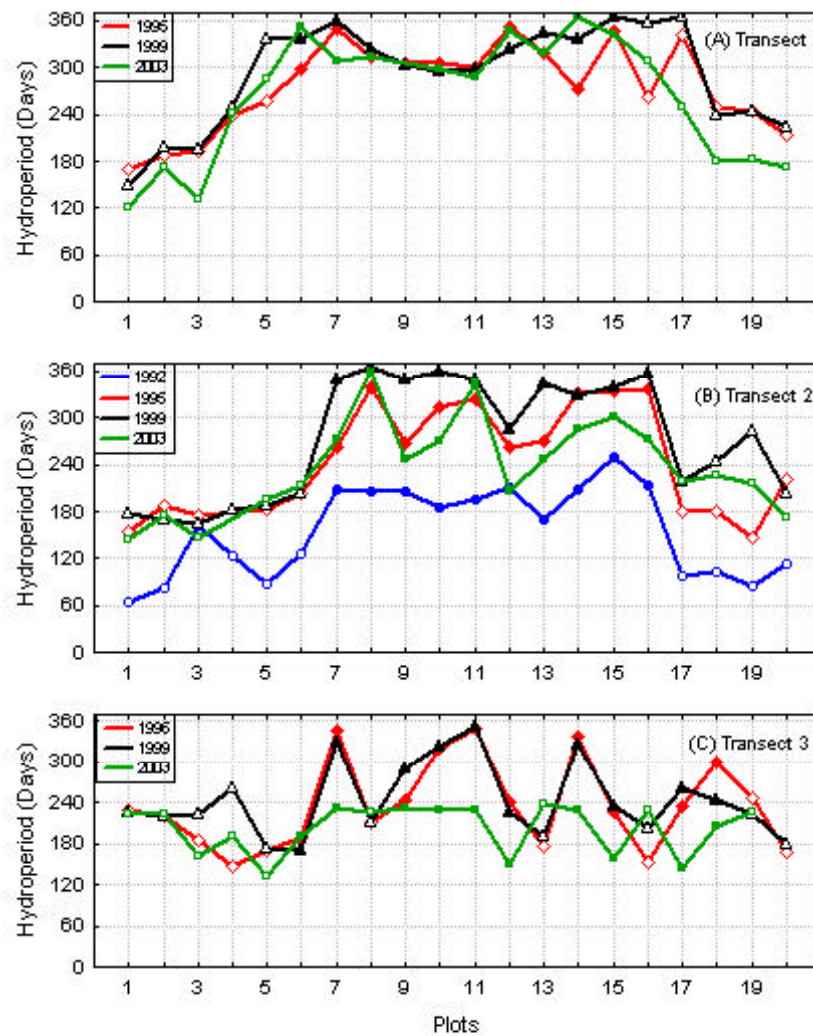
Figure 11. Plot level vegetation-inferred hydroperiods estimated in Muhly and Cladium plots along the
Transects 1,2 and 3, 1992-2003. Open symbols= Muhly plots; Closed symbols – Cladium plots
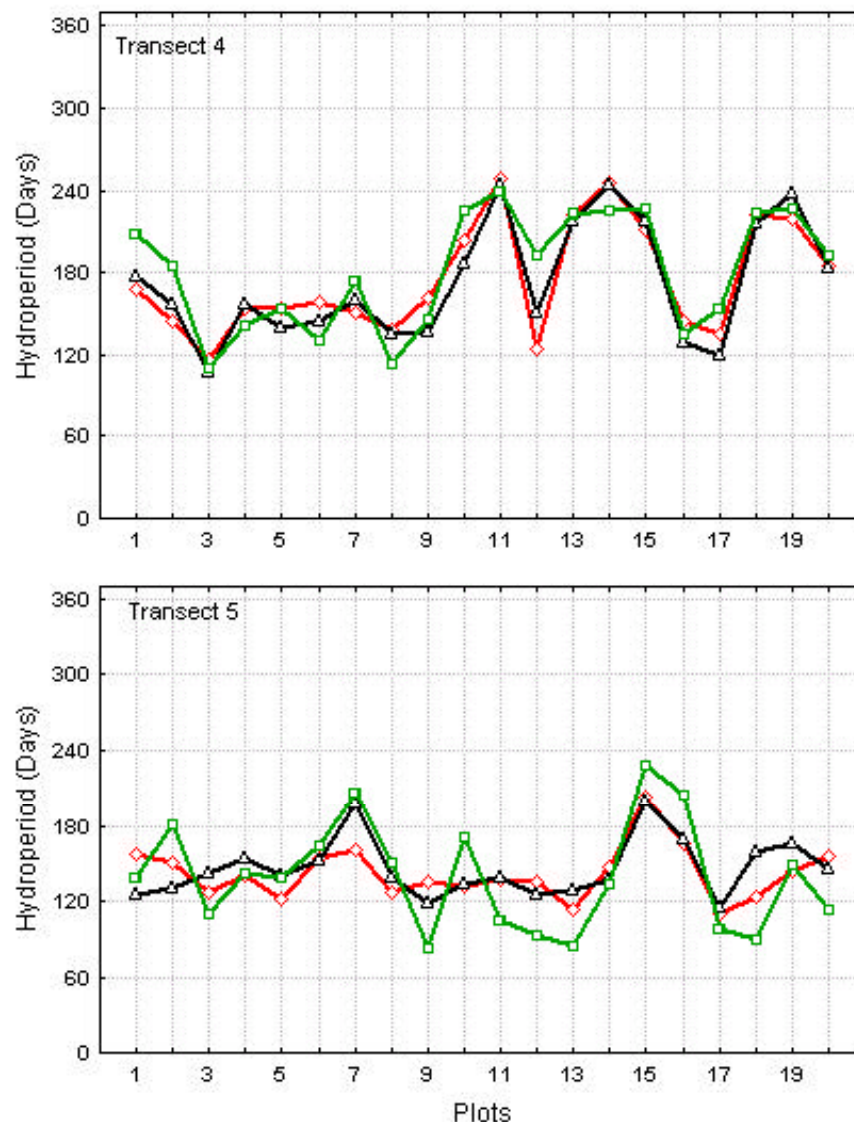
Figure 12. Plot level vegetation-inferred hydroperiods estimated along the Transects 4 and 5 in 1997 (red), 1999 (black) and 2003 (green)

During the S-332 operation and ISOP periods, temporal changes in vegetation-inferred hydroperiods were substantial, especially on Transects 2 and 3 (Figure 11). On Transect 1, inferred hydroperiods did not differ significantly between 1995 and 1999 (echoing the ANOSIM results presented in Table 2), but inferred hydroperiods in 2003 were shorter than in 1999, particularly in the M-plots (Figure 11a; Table 4). On Transect 2, inferred hydroperiods were significantly longer in 1995 and 1999 than in 1992 (M- and C-plots) and 2003 (C-plots only) (Figure 11b). Inferred hydroperiods along Transect 3 did not differ significantly between 1996 and 1999, but were shorter in 2003 than either of the previous years, mainly in the C-plots. The shorter inferred hydroperiods on all three transects in 2003 in comparison to 1995 and 1999 (Figure 11c) provide strong correlative evidence that the decrease in Taylor Slough water level during the ISOP period (Figures 3 and 4) was responsible for the vegetation change in this portion of Taylor Slough.

20

The vegetation-inferred hydroperiods for Transect 4 and 5 are presented in Figure 12. Among-year differences in inferred hydroperiods were not significant on either transect. In conjunction with the ANOSIM results, which did indicate significant among-year differences in vegetation, these analyses suggest that factors other than hydrology were responsible for vegetation change in the headwater portions of Taylor Slough.

Table 4: p-values from repeated-measures ANOVA testing for effects of plot-type (M- and C-plots, on Transects 1-3), Transects (T4 & T5) and year (1992-2003) on vegetation-inferred hydroperiod.

Transect	Plot-type	Year	Plot-type x Year
1	<0.001	0.005	0.015
2	<0.001	<0.001	0.049
3	0.005	<0.001	<0.001
	Transect	Year	Transect x Year
4 & 5	0.003	0.902	0.139

5. Summary and Conclusions

In 2003, we re-sampled a vegetation network that had been established in 1979 and surveyed periodically through 1999. Our analysis of vegetation dynamics over the 24-year study period addressed changes undergone by individual plant species and by the resident marsh communities in the heterogeneous Taylor Slough landscape. The interpretation of these changes was aided by a careful analysis of the hydrologic record at these sites, and the application of a recently developed WA regression and calibration model for vegetation-hydrology relationships in the marl prairies of ENP and Big Cypress National Preserve (Ross et al. 2003).

Since the onset of S-332 operations in 1980, water management in Taylor Slough raised marsh water levels above what they would have been under the structural and regulatory framework of the previous two decades. Water levels were particularly affected during 1992-1999, when they were elevated in most years by 30-40 cm at Taylor Slough Bridge. More recently, during the 1999-2003 period, water levels in Taylor Slough dropped slightly in response to ISOP management.

We examined vegetation change along five transects. Three transects established in 1979 were south of S-332 and S-332D, and presumably influenced by them (Transects 1-3). One transect established in 1997 was west of these structures and possibly under their influence (Transect 5). The last transect, also set up in 1997, was near Context Road, north of the likely zones of influence of S-332 and S-332D (Transect 4). The composition of all three southern transects changed in a similar direction after 1979. Muhly (*M. filipes*) was replaced by sawgrass (*C. jamaicense*), while the latter was replaced by hydric species such as spikerush (*E. cellulosa*), which emerged as a dominant plant. These changes were mostly in place by 1995-96, but continued through 1999. Subsequently, there was evidence of a reversal in these long-term trends during the ISOP period (1999-2003). The vegetation north and west of S-332 and S-332D also underwent substantial

21

year-to-year variation during the period 1997-2003, but these temporal patterns differed somewhat from those observed further south. The two northern transects were characterized by an increase in total cover, an increase in the dominance of both muhly and sawgrass, and a decrease in the importance of minor species from 1997 to the present.

Application of the WA model to these data confirmed that during the 1990's vegetation composition south of S332 became more like that found in long hydroperiod marshes, but during the ISOP period it returned part of the way toward its 1979 condition, i.e., a community characteristic of less prolonged flooding. This pattern was especially evident on Transect 2, immediately north of the Main Park Rd. In contrast, the vegetation change observed along two northern transects since 1997 showed no evidence of change in hydrologic condition.

The following lessons and caveats may be drawn from the Taylor Slough vegetation record:

1. There was a definite change in Taylor Slough hydrology over the period 1979-2003, and water management was responsible. Delivery through S-332 created wetter conditions for much of the period; when this delivery system was replaced by S-332D during ISOP, water levels declined. A lag term representing carryover from the previous season disappeared in our model during the S-332 operation period, suggesting that storage was not an important element in the hydrologic budget under this management regime. Hopefully, continued implementation of the current ISOP operations will replace this storage function, and reduce sudden reversals in water level.

2. In this study, changes in plant species composition in the marl prairie environment appeared to track hydrologic change closely, with little discernible lag period. This is a surprising result, because many of the dominant species are long-lived perennials, known to spread vegetatively through rhizome formation, and seedling establishment that could lead to rapid vegetation change is considered to be a rare occurrence, usually associated with disturbance. The process of vegetation dynamics deserves to be examined further, at more sites, at spatial scales smaller and larger than those addressed here, based on more frequent observations. In this study, the responses of vegetation to hydrologic change were not uniform within transects, with low and high elevation sites exhibiting different behavior. One should therefore not presume that vegetation in other Everglades environments, for instance, the Ridge and Slough complex, would track hydrologic changes of similar magnitude as closely.

3. Hydrologic variation can affect plant species diversity substantially. In this study the long-term wetting trend in Taylor Slough led to a decrease in species richness, a trend that was partially reversed during the ISOP period in some transects. These patterns were due in large part to the high relative species richness of short hydroperiod marshes in comparison to their long hydroperiod counterparts.

4. While hydrology may be the primary forcing variable on Everglades marsh vegetation composition, other factors may arise as important drivers from time to time. The most prominent of these is fire, which interacts with hydrology in many ways to reset the successional clock, thereby creating the habitat mosaic we see at any point in time (e.g., Herndon et al. 1991; Lockwood et al. in press). Marl prairies in the East Everglades have burned frequently in last few decades, at times and under conditions that may differ from the historical norm (Pimm et al. 2002). A more complete analysis of vegetation in this area should incorporate fire history. More significantly, CERP planning should incorporate fire with hydrology in a substantive, seamless, and administratively tenable manner.

5. Finally, the Weighted Averaging approach taken here, in conjunction with a good understanding of the hydrologic record, appear to be an effective means of examining vegetation dynamics in response to hydrologic change.

6. Literature Cited

Alexander, TR and AG Crook. 1975. Recent and long term vegetation changes and patterns in South Florida, Part II, Final Report, South Florida Ecological Study, Appendix G, NTIS PB 264462, University of Miami, Coral Gables, FL.

Armentano, TV, DT Jones and BW Gamble. 2000. Recent patterns in the vegetation of Taylor Slough. P. 187 *In* Proceedings of Greater Everglades Ecosystem Restoration Science Conference. Naples FL. (abstract).

Birks H.J.B, J.M. Line, S. Juggins, A.C. Stevenson and C.J.F. ter Braak. 1990. Diatoms and pH reconstruction. *Phil. Trans. R. Soc. Lond. B* 327: 263-278.

Busch, DE, WF Loftus and OL Bass, Jr. 1998. Long-term hydrologic effects on marsh plant community structure in the southern Everglades. *Wetlands* 18 (2): 230-241.

Childers, DL, RF Doren, R Jones, GB Noe, M Rugge and LJ Scinto. 2003. Decadal change in vegetation and soil phosphorus pattern across the Everglades landscape. *Journal of Environmental Quality* 32: 344-362.

Clarke, KR. 1993. Non-parametric multivariate analyses of changes in community structure. *Australian Journal of Ecology* 18: 117 – 143.

David, PG. 1996. Changes in plant communities relative to hydrologic conditions in the Florida Everglades. *Wetlands* 16 (1): 15-23.

Davis, SM, LH Gunderson, WA Park, JR Richardson and JE Matson. 1994. Landscape dimension, composition, and function in a changing Everglades ecosystem. *In*: Davis, S.M. and Ogden, J. (eds.), *Everglades: The Ecosystem and Its Restoration*. pp 419-444. St. Lucie Press, Delray Beach, Florida, USA.

Herndon, A., L. Gunderson and J. Sternberg. 1991. Sawgrass (*Cladium jamaicense*) survival in a regime of fire and flooding. *Wetlands* 11 (1): 17 – 28.

Juggins. S. 2003. C^2 User guide. Software for ecological and palaeoecological data analysis and visualization. University of Newcastle, Newcastle upon Tyne, UK. 69pp.

Kolipinski, MC and AL Higer. 1969. Some aspects of the effects of quantity and quality of water on biological communities in Everglades National Park. Open File Report, USGS, Tallahassee, FL.

Kruskal, JB. 1964. Nonmeteric multidimensional scaling: a numerical method. *Psychometrika* 29: 1-27.

Lockwood, JL, MS Ross and JP Sah. 2003. Smoke on the water: The interplay of fire and water flow on Everglades restoration. *Frontiers in Ecology*. In press.

McCune, B. and JB Grace. 2002. *Analysis of Ecological Communities*. MjM Software Design. Gleneden Beach, Oregon, USA.

McCune, B. and MJ Mefford. 1999. PC-ORD. Multivariate Analysis of Ecological Data. Version 4.0. MjM Software, Gleneden Beach, Oregon, USA.

Nott, MP, OL Bass, Jr., DM Fleming, SE Killeffer, N Fraley, L Manne, JL Curnutt, TM Brooks, R Powell and SL Pimm. 1998. Water levels, rapid vegetational changes, and the endangered Cape Sable Seaside Sparrow. *Animal Conservation* 1: 23-32.

Olmsted, IC, LL Loope and RE Rintz. 1980. A Survey and Baseline Analysis of Aspects of the Vegetation of Taylor Slough, Report T-586. South Florida Research Center Everglades National Park. U. S. National Park Service.

Olmsted, I. and TV Armentano. 1997. Vegetation of Shark Slough, Everglades National Park. SFNRC Technical Report 97-001. South Florida Natural Resource Center, Everglades National Park, Homestead, Florida, USA.

Pimm SL, JL Lockwood, CN Jenkins, JL Curnutt, MP Nott, RD Powell and OL Bass Jr. 2002. Sparrow in the grass: a report on the first ten years of research on the Cape Sable Seaside Sparrow (*Ammodramus maritimus mirabilis*). Everglades National Park, Homestead, FL.

Ross, MS, JF Meeder, JP Sah, PL Ruiz and GJ Telesnicki. 2000. The Southeast Saline Everglades revisited: 50 years of coastal vegetation change. *Journal of Vegetation Science* 11: 101-112.

Ross, MS, DL Reed, JP Sah, PL Ruiz and MT Lewin. 2033. Vegetation: environment relationships and water management in Shark Slough, Everglades National Park. *Wetland Ecology and Management*. In press.

Ross, MS, JP Sah, PL Ruiz, DT Jones, H Cooley, R Travieso, JR Snyder and C Schaeffer. 2003. Effect of hydrologic restoration on the habitat of the Cape Sable seaside sparrow: Annual report of 2002-

2003. Everglades National Park, June 2003.
http://www.fiu.edu/~serp1/projects/capesable/2003_CSSS_Annual_Report.pdf

Van Lent, TJ, R Johnson and R Fennema. 1993. Water management in Taylor Slough and effects on Florida Bay. Technical Report SFNRC 93-03, ENP, Homestead, FL.

Van Lent, TJ, RW Snow and FE James. 1999. An examination of the Modified Water Deliveries Project, the C-111 Project, and the Experimental Water Deliveries Project: hydrologic analyses and effects on endangered species. SFNRC, ENP, Homestead, FL.